Phenix Center Section Upgrade

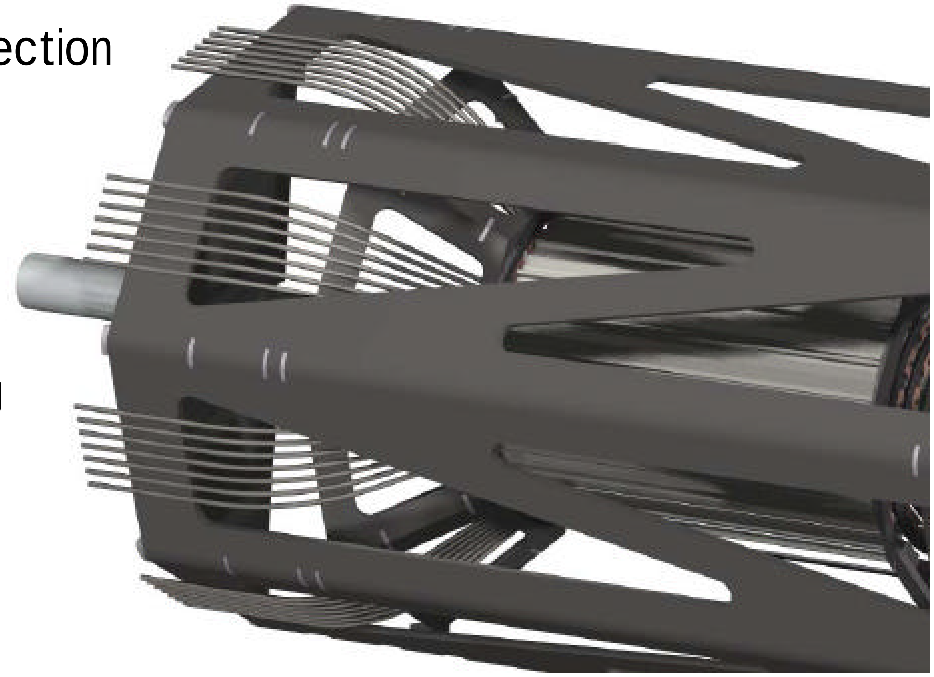
December 16, 2002

Presented By

Steve Ney, William O. Miller, & Roger Smith

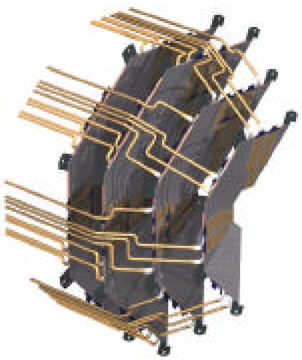
Presentation Content

- Review of Phenix Silicon Tracker System Requirements
- Phenix Tracker Concept
  - Design
    - General Layout
    - Structural Material Selection
    - Structural Analysis
      - Modal analysis
    - Cooling Analysis
      - Coolant candidates
      - End Cap Pixel Cooling
- Future R&D Issues
- ROM Cost Mech./Cooling Cost

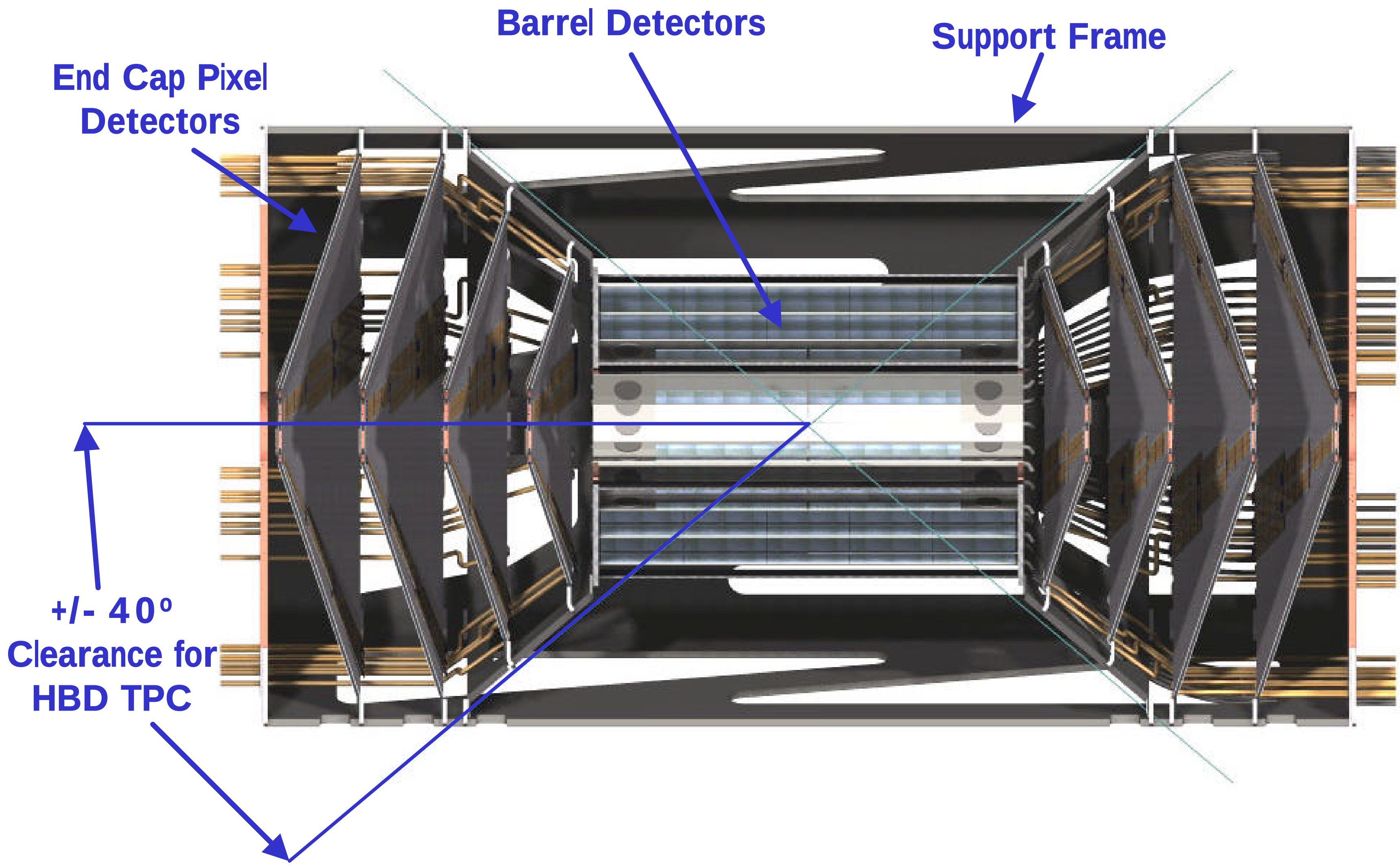


Design Requirements

- Silicon/Pixel Detector
  - System Requirements:
    - Clamshell Design:
      - Separates into two halves along the vertical axis
    - Detector Coverage:
      - Hermeticity: single overlap circumferentially
      - 160° coverage in each half of barrel section
        - » 4 layers of pixels and/or strip detectors
      - 180° coverage in each half of the end cap sections
        - » 4 layers of pixel detectors
    - +/- 40° Envelop for HBD TPC maintained around barrel section
      - End cap pixel disks, utilities, and barrel detector end support are outside of envelop
      - Main clamshell support structure is inside of envelop, but less than 0.5% RL
    - RL of 1% or less for each detector layer (includes: detectors, structure, and utilities)
    - Dimensional and structural stability of less than 25 µm
    - Utility Routing:
      - Along barrel end support for barrel region
      - Radial at pole tips for the end caps
    - Mounting of Tracker:
      - Off of magnet pole tips
      - Tracker to behave as a rigid body structure
    - Operating Temperature: Room temperature (or possibly 0° option?)

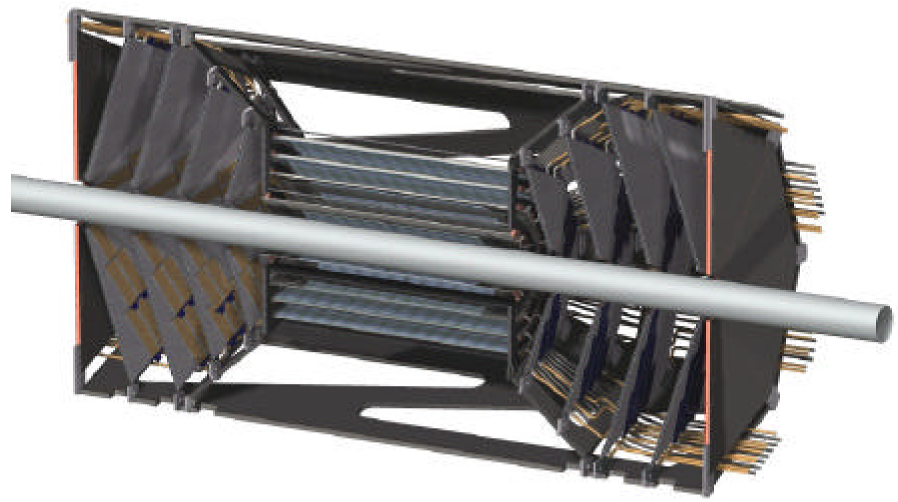


General Layout for Phenix Tracker Concept



Phenix Tracker Construction

- Primary Concept:
  - Sandwich composite construction
    - GFRP facings
    - GFRP HC core
    - Less than 0.5% RL for sandwich
  - Octagon structure
  - Composed of flat panels
  - Clamshell structural halves joined to form integrated structure around beam line



Phenix Tracker Concept Study Analysis

- Look at 3 areas:
  - Material selection
    - RL, α, ρ, E.
  - Detector support frame
    - Stiffness comparison
      - Modal analysis
  - Cooling utilities
    - Coolant types
    - Sized hardware
    - Single phase cooling (with two phase cooling option if judged necessary)

Material Selection

Material[1]	Radiation Length (eff.) (cm)	Elastic Modulus (GPa)	Density (g/cm³)	CTE (ppm/K)
GFRP[a]	25.0	311.7	1.68	-1.13
Beryllium	35.4	290	1.84	11.6
Carbon-Carbon[b]	23.0	496	1.7 - 1.85	-1.5
Silicon	9.37	131	2.33	2.6
Aluminum	8.89	68.9	2.7	23.6

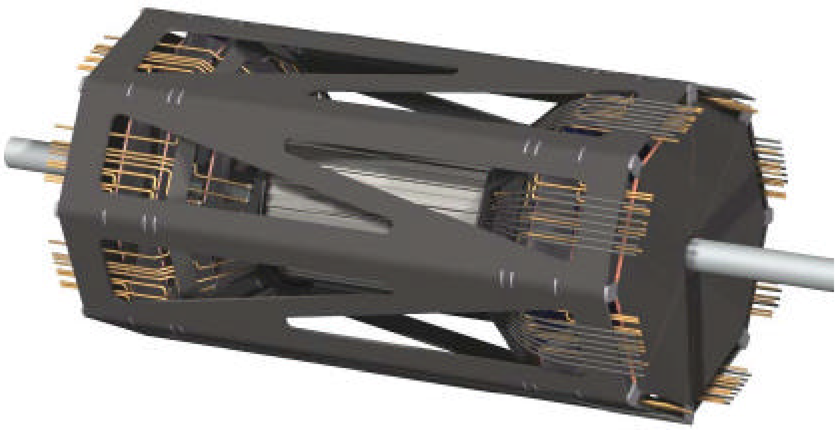
[a] P75/epoxy, unidirectional properties, ~60% Fiber

[b] Unidirectional properties (P120 equivalent)

[1] Miller, W.O., et. Al., *Superconducting Super Collider Silicon Tracking Subsystem Research and Development*, LA-12029, 1990.

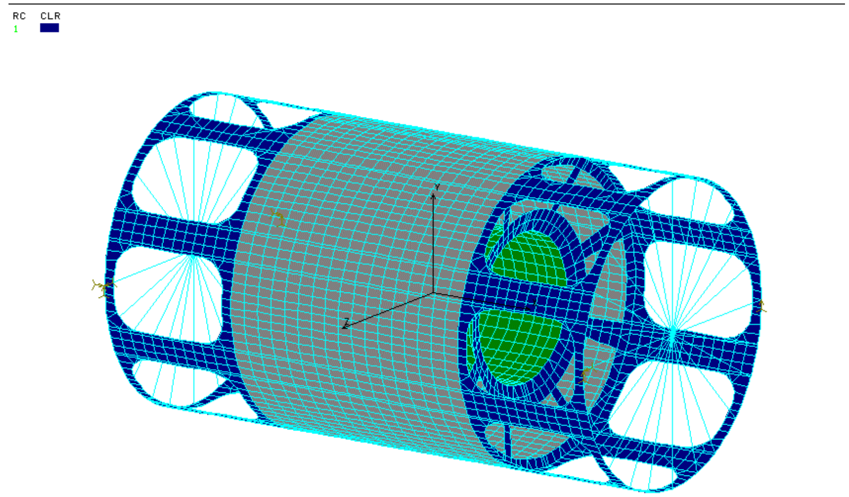
Material Selection

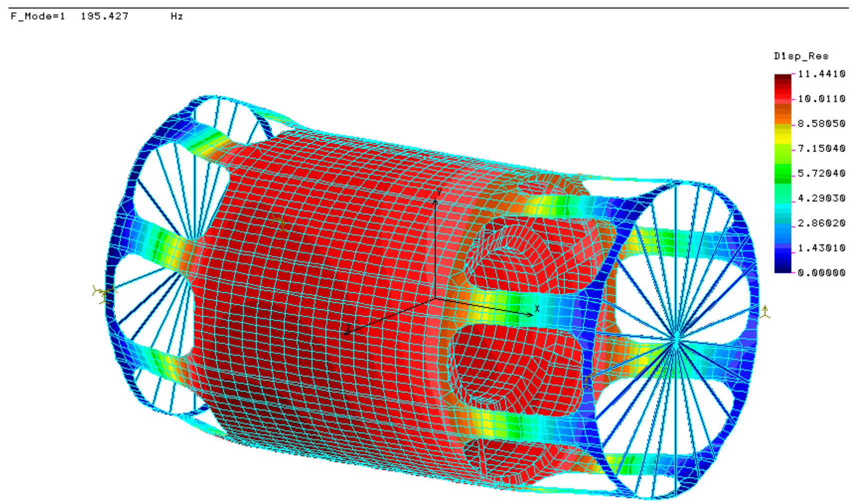
- GFRP's stiffness to weight ratio is ~18% greater than Beryllium
- GFRP's RL is about 70% of Beryllium's RL
- GFRP provides the necessary stiffness to meet the 25 µm stability requirement, while still meeting the stringent 1% RL requirement set for the Phenix tracker
- GFRP more easily machined and fabricated into complex parts than Beryllium due to the carcinogenic nature of Beryllium dust and fumes



Detector Support Frame

- Modal Analysis
  - FE Trend Study
    - Multiple concepts analyzed
    - Vary geometrical dimensions
    - Vary detector mass
  - Build structural matrix
    - Want to achieve first fundamental mode of the weighted structure in the 70 - 100 Hz
    - Assumed weighted structure has 6 times the mass of a unloaded structure
    - Based upon preliminary results of primary concept
      - Unloaded Structure, 195 Hz
      - Loaded Structure, 81 Hz
- Static Analysis - in process
  - Torsional stiffness

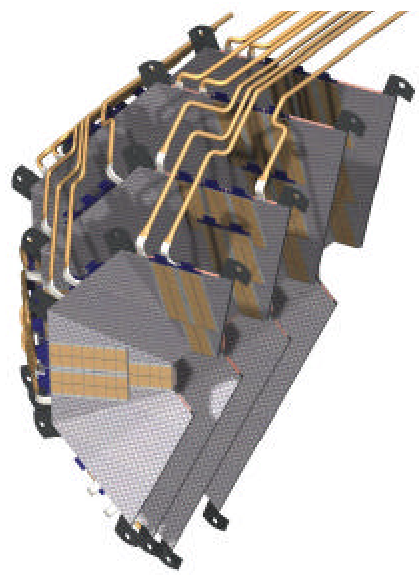




PHENIX Pixel Detector Cooling

- Objectives
  - Focus on thermal and mechanical issues related to cooling, in terms of stability guidelines
  - Size key cooling elements
  - Choose coolant and delivery temperature
  - Estimate module and structure temperature

Barrel Clamshell



End Cap Clamshell

PHENIX Pixel Cooling

- Study Scope
  - Size cooling passages for barrel and end cap
    - End cap terminology: disk (sectors) make up clamshell
  - Preliminary thermal analysis of structure
    - 1st order approximation for temperature distribution
    - Estimate thermal distortions from temperature gradients
- Cooling Considerations
  - Single phase fluid, compatible with detector electronics,
  - **Base study on <u>turbulent flow</u>**
    - Select a single candidate from the per-fluorocarbon family (Fluorinerts)
  - Determine
    - Can a single phase fluid handle the heat load, with acceptable hydraulic and thermal performance
    - What will be the temperature distribution?
    - What is the radiation length penalty for this approach?

Coolant Candidates

Four fluorinert fluids from 3M listed below; two used for low temperature two-phase flow.

C_3F_8 used in ATLAS Pixel Detector in 2-phase flow

C_5F_{12} and C_6F_{14} both suitable for PHENIX, in single or 2-phase

Using C_5F_{12} for preliminary calculations. Data readily available from NIST, and radiation length is 4% higher than C_6F_{14}

Coolant	Saturation Temperature (°C)	Specific Heat (kJ/kg-°K)	Density (kg/m^3)	Latent Heat of Vaporization (kJ/kg)	Thermal Conductivity (W/mK)	Viscosity (mPa-s)
C_5F_{12}	29.75	1.090	1597.2	91.89	0.0425	305.04
C_4F_{10}	-2.09	1.029	1591.3	96.96	0.0470	305.25
C_3F_8	-36.6	0.968	1604.1	104.78	0.0651	313.8
C_6F_{14}	56	1.088	1680.0	87.9	0.0545	450
CH_3OH	64.4	2.825	748.4	1101.2	0.306	503.6

Ultimately, the higher thermal conductivity of C_6F_{14} may favor this fluid over our initial choice; we will check this later

Coolant Comments

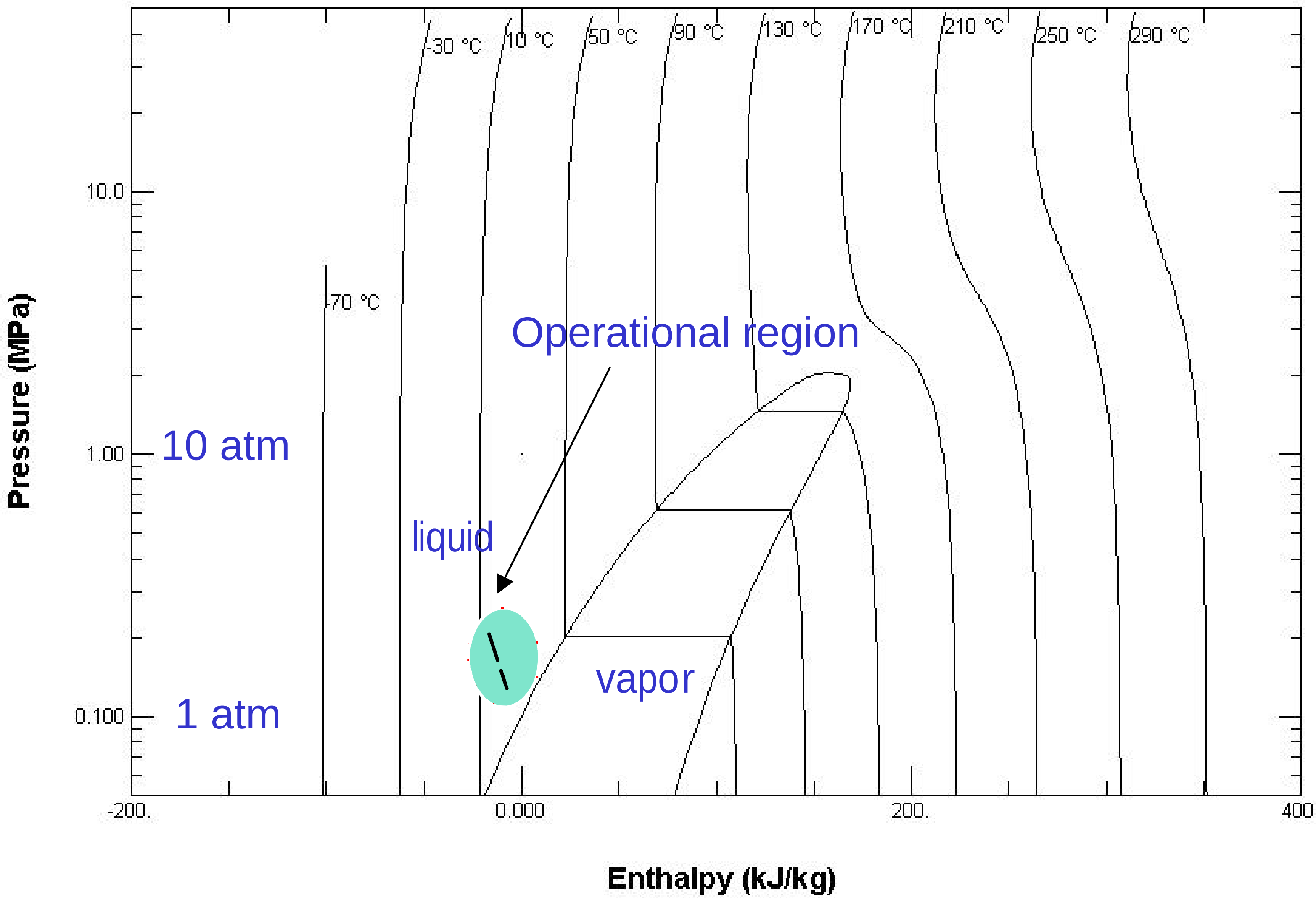
- Single Phase versus Two-Phase Flow
  - Prefer using single phase for reasons of simplification
  - Two-phase coolant system as presently being adapted to HEP detector applications uses pressure regulation on all inlets and outlets, involving additional control system complexities that would be avoided by sticking with single-phase flow
  - Thermal and fluid analyses will focus on C_5F_{12} first, as:
    - Sensible heat pick up same as for C_6F_{14}
    - Radiation length better by 4%
    - Viscosity, which controls pressure drop is lower by 32%
    - Fluid property data available on disk.
- If we elected to change to two-phase flow either candidate would be acceptable

Pixel Cooling

- Cooling considerations (continued)
  - Set the fluid inlet temperature to 20°C for initial calculations
  - Must be above dew point of detector space to avoid condensation
    - Dew point probably on order of 13°C
  - Option for operation at 0°C was requested
    - At what point will decision be made?
  - Fluid inlet pressure
    - Sufficiently high as to prevent phase change in return line
    - Limitation on pressure set by desire to avoid induced strains in lightweight thermostructures
      - High pressure poses unnecessary strain on modules
    - 1st order decision to limit pressure 1 to 2 atmospheres differential
      - Requires proof testing coolant tubes to nominally 1.5 to 3 atmospheres
      - ATLAS Pixel Detector is proof testing in excess of 10 atmospheres differential
  - Heat loads: Barrel region, 1.56kW, End Cap 0.7kW, for total of 2.26kW

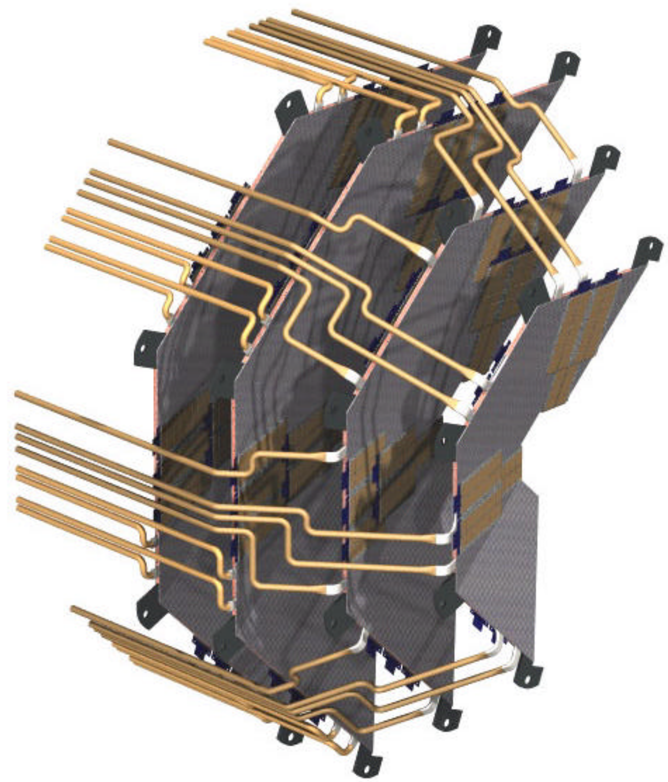
Pixel Cooling With Fluorinerts

Fluid C_5F_{12}



End Cap Region

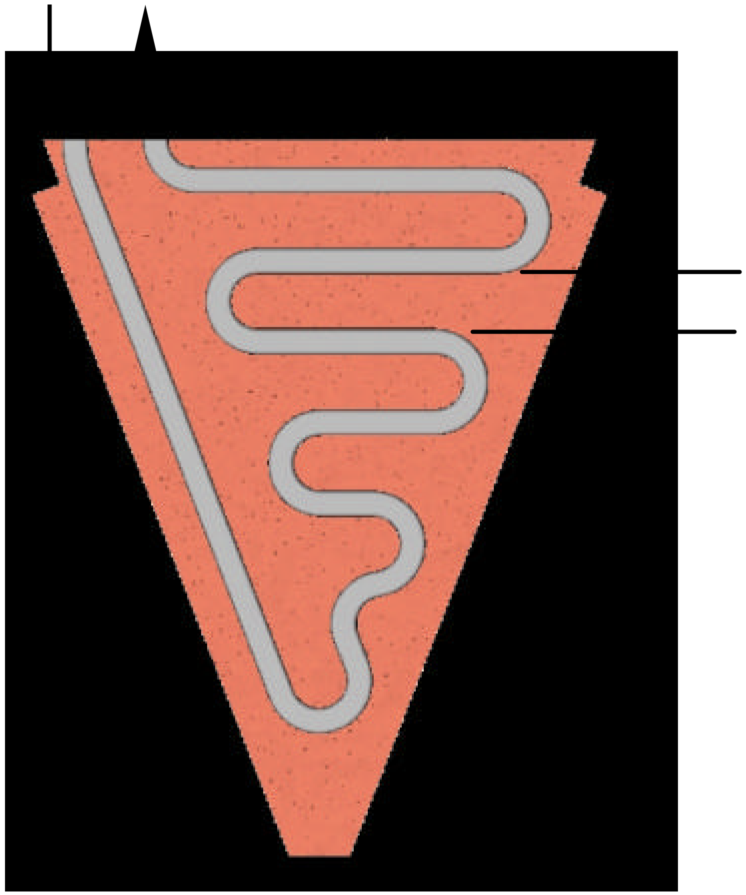
- Objective
  - Determine thermal and cooling solution for End Cap Region
- Terminology
  - Substructure, half disk composed of flat panel segments, called sectors
- Cooling
  - Consider series cooling of two sectors, providing modularity of 2
  - Cooling circuit failure confined to adjacent sectors



End Cap Sector

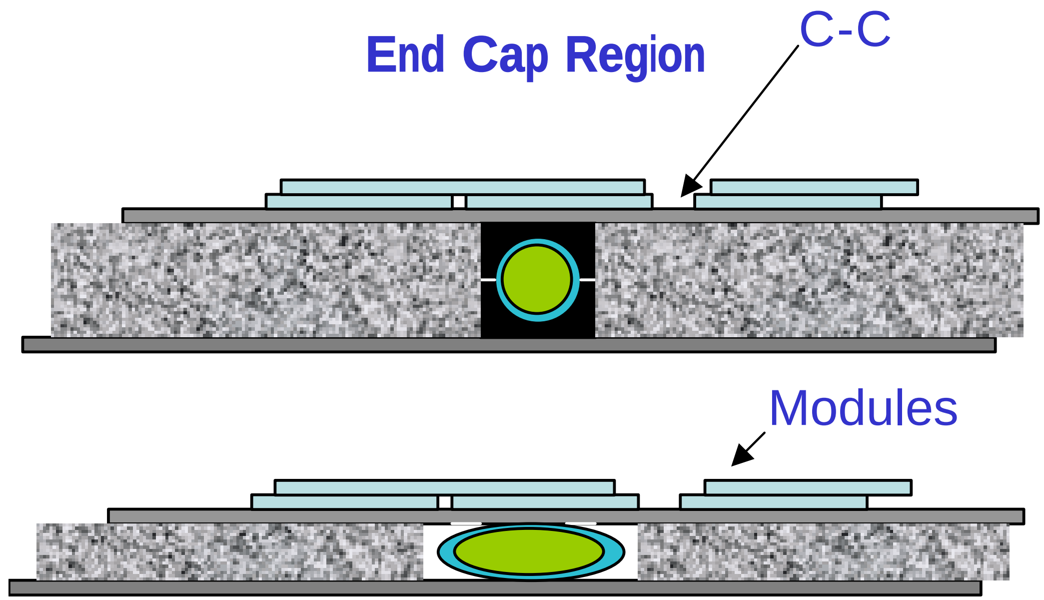
- Objective of Thermal/cooling Analysis
  - Establish path geometry that will provide uniform cooling of the distributed pixel module heat load
  - Verify practicality of a series connection of two sectors
    - Using single phase flow
- Preliminary sector results
  - Largest sector, nominally 15W
  - 2mm diameter tube, or rectangular passage, <u>*two sectors in series*</u>
  - Bulk fluid temperature rise, 2.8C (30W)
  - Film wall temperature, 2C
  - Pressure drop for pair, 3.6psi,

Meandering tube geometry



Composite Thermostructures

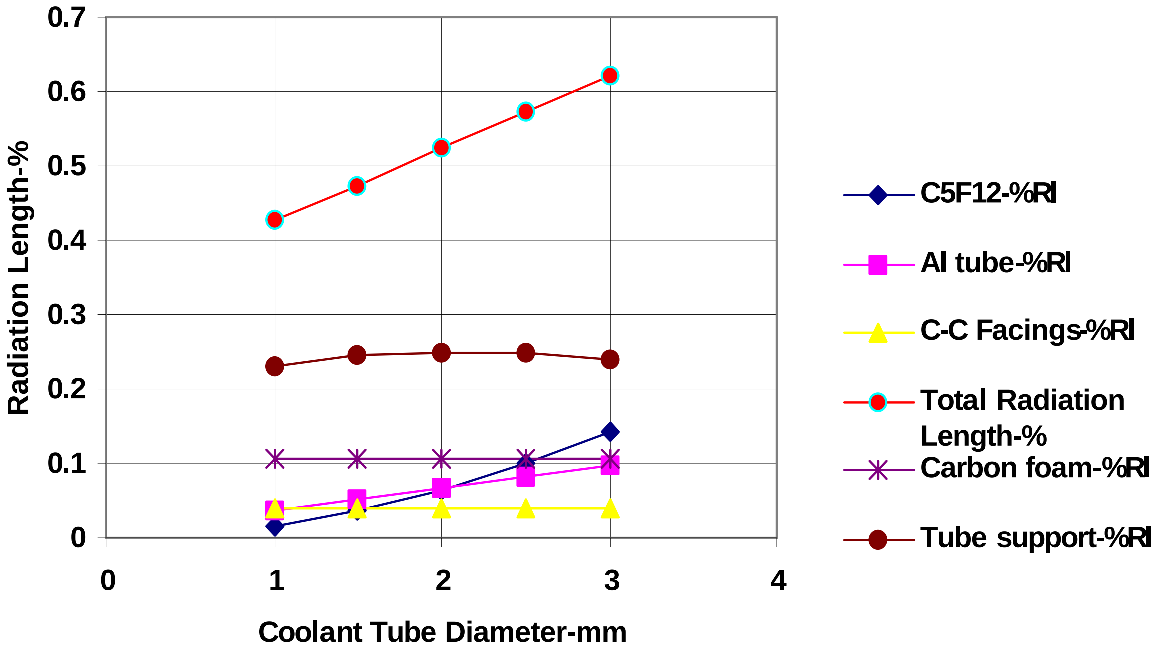
- Construction Options
  - Circular tube requires tube support, but tube terminations are simpler
  - Flattened tube provides better heat transfer in high heat flux applications, but more complex tube connections
  - Carbon-carbon facings for high K_t



Options for constructing thermostructures

Barrel region

End Cap Sector Circular Tube



- Typical summary chart describing radiation length as function of coolant tube size
- Tentative choice for circular tube geometry requiring tube support is 2mm inner tube diameter

End Cap Sector-Estimated Thermal Gradients

Tube ID mm	DT$_{0-1}$ (°C)	DT$_{1-2}$ (°C)	DT$_{2-3}$ (°C)	DT$_{3-4}$ (°C)	DT$_{4-5}$ (°C)	DT$_{5-6}$ (°C)	Sum (°C)
1.0	**3.81**	**0.016**	**0.93**	**0.033**	**0.46**	**2.27**	**7.52**
2.0	**1.97**	**0.008**	**0.51**	**0.023**	**0.46**	**2.27**	**5.24**
2.5	**1.61**	**0.007**	**0.42**	**0.02**	**0.46**	**2.27**	**4.79**
3.0	**1.36**	**0.006**	**0.36**	**0.017**	**0.46**	**2.27**	**4.47**

Largest gradients in coolant film and sandwich facing

- ? T_{0-1}: Coolant film temperature drop at the tube containmentwall
- ? T_{1-2}: Temperature drop through tube wall material
- ? T_{2-3}: Temperature drop through adhesive, or thermal grease surrounding tube
- ? T_{3-4}: Temperature drop of tube interfacing material
- ? T_{4-5}: Temperature drop through sandwich facing to tube interfacing material
- ? T_{5-6}: Temperature gradient in sandwich facing from the electronic chip to the cooling tube location
- ? T_{6-7}: Temperature drop in the adhesive used to mount the module chip to the sandwich facing

PHENIX Cooling

- Study is progressing as planned
  - Barrel preliminary cooling study is in progress
  - Matter of focusing on low mass ladder concept with embedded cooling tube
- Single phase fluorinert fluid is quite adequate for cooling because of the low heat load in both End Cap and Barrel Regions, <u>proviso turbulent flow</u>
- Recommend continuing with assumption of liquid based cooling
  - Radiation length of thermostructures with this fluid is within acceptable bounds
- Timely decision on any desired lower range of temperature would be helpful
  - Assemble and operate at essentially room temperature offers distinct structural and stability advantages

Future R&D Issues

- Structural Design
  - Develop Alignment and/or Attachment of:
    - Phenix tracker to beam line and magnet poles
    - Structural clamshell halves to one another
    - End Cap disks to structural support
    - Barrel ladders to structural support
    - Analyze with FE model the stiffness variation in the structure with attachment concepts
  - Build Prototype of End Cap Disk Sector
    - Test structural stiffness
  - Build Prototype of Outer Support Structure
    - Test clamshell connections & structural stiffness
- Cooling Design
  - Each detector concept brings slightly different issues
  - End Cap as an example:
    - Composite half structure, resembling an incomplete conical frame
    - Embedded cooling channel, possibly with two sub-structures with series connection of the coolant
    - Programmatically prudent to construct a half disk composite sandwich and to populate the entire structure with Kapton foil heaters for thermal/mechanical testing
      - Test stability of the mounting concept under thermal loading
  - Barrel Region
    - Has advantage that ladder concepts have been tested
    - However, PHENIX ladder may move toward a lower mass, lower % radiation length concept
    - If so, detailed FEA and prototype testing would be suggested along the lines of the End Cap Proposal